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(54) Cubic boron nitride-base sintered ceramics for cutting tool

Sinterkeramik auf Basis von kubischem Bornitrid für Schneidwerkzeuge

Céramiques frittées à base de nitrure de bore cubique pour l'outil de tournage

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(73) Proprietor:
MITSUBISHI MATERIALS CORPORATION
Chiyoda-ku, Tokyo 100 (JP)

(72) Inventors:
• Ueda, Fumihito,
c/o Chuo-Kenkyusho
Omiya-shi, Saitama-ken (JP)
• Tazima, Itsurou,
c/o Chuo-Kenkyusho
Omiya-shi, Saitama-ken (JP)

• Yageta, Masayuki,
c/o Chuo-Kenkyusho
Omiya-shi, Saitama-ken (JP)

(74) Representative:
Hansen, Bernd, Dr. Dipl.-Chem. et al
Hoffmann Eitle,
Patent- und Rechtsanwälte,
Postfach 81 04 20
81904 München (DE)

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• JOURNAL OF HARD MATERIALS vol. 2, no. 3-4,
1991, pages 233 - 243 F. UEDA ET AL.
'Microstructure and mechanical properties of
cBN-TiN composites'

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Description

BACKGROUND OF THE INVENTION

TECHNICAL FIELD

The present invention relates to cubic boron nitride-base sintered ceramics for cutting tool. The sintered ceramic is such that the ceramics do not suffer cutting edge damage and chipping even when used under severe conditions such as high speed or high feed rate interrupted cutting of hardened steels, and their cutting edge exhibits an excellent resistance to wear.

BACKGROUND ART

Cubic boron nitride (denoted as c-BN below)-based ceramics sintered under high pressure and high temperature are known.

For example publication of unexamined J.P. Patent Application Laid Open No. 55-62862 discloses a c-BN ceramics sintered under high pressure and having 10% to 60% by volume of one or more of titanium carbide, titanium nitride, and titanium carbonitride (denoted hereunder as TiC, TiN and TiCN) as a bonding phase, 0.1% to 18% by volume of aluminum oxide (denoted hereunder as Al_2O_3) as a bonding phase, and the remainder of c-BN as a dispersed phase, and unavoidable impurities (note: in the above and the following, percentage refers to percentage by volume).

Furthermore, the use of cutting tips formed from this high pressure sintered ceramic for finishing cutting of ceramics such as hardened steels having a Rockwell hardness (C scale) of 55-62, and for finish cutting of materials such as nickel or cobalt based super alloys is well known.

On the other hand, in recent years the increase in the performance of cutting machines has resulted in remarkable labor savings together with a trend toward higher cutting speeds and heavier cutting. With the beforementioned cutting tips however made from c-BN high pressure sintered ceramics, the strength of these tips is inadequate. Especially for high speed interrupted cutting of high strength steels such as case carburized hardened steels and high frequency hardened steels, or for cutting under severe conditions such as high feed interrupted cutting. Moreover, due to this lack of strength, the cutting edge of the cutting tip is susceptible to cracking and chipping resulting in unsatisfactory cutting performance.

In the Journal of Hard Materials, Vol. 2, 1991, page 233, Ueda et al. describe a sintered compact for use in tools. The compact comprises 80 to 95 Vol. % of high pressure form boron nitride having an average particle size of less than 10 microns. The balance is a matrix comprising at least one binder material selected from carbides, nitrides and carbonitrides of group IVa and Va transition metals. The content of aluminium in the matrix is indicated to be 5 to 30 weight % and the particles therein are of a size of less than 1 micron.

In UK patent application GB-A-2048956, a sintered compact for use in an ultrahard tool is revealed. The compact comprises 20 to 80 vol. % of high pressure form boron nitride and a residual consisting of Al_2O_3 or a compound ceramic principally comprising Al_2O_3 which may contain carbides or nitrides of group IVa, Va and VIa metals. The residual part is indicated to constitute a continuous phase in the structure of the sintered compact.

The present inventors have studied the beforementioned conventional cutting tips manufactured from c-BN ceramics sintered under high pressure, from the view point of the above situation and has conducted experiments aimed at improving the strength. Results (1), (2) and (3) of these experiments are given below.

(1) With the conventional cutting tip manufactured from c-BN high pressure sintered ceramics, it was found that the crystal grain sizes of one or more of the TiC, TiN, TiCN and Al_2O_3 forming the bonding phase exceeded a maximum grain size of 3 microns. The reason for the large crystal grain size was considered due to the fact that even when manufacturing the cutting tip using minute grain sizes of less than 1 micron for the raw material powder, grain growth occurred during the high pressure sintering. Consequently, with the existence of crystal grain sizes in the bonding phase exceeding a maximum grain size of 3 microns, sufficient strength could not be maintained.

(2) In the above case, it was ascertained that even though grain growth occurred in the bonding phase, the high pressure sintering process had practically no influence on the crystal grain size of c-BN. Accordingly, if a c-BN powder having a crystal grain size of not more than 1 micron was used for the raw material powder, the c-BN crystal grain size remained below 1 micron even after the high pressure sintering process.

(3) On the other hand, when using one or more of titanium and aluminum nitride, carbide or carbonitride compounds (denoted hereunder as $Ti_{2-3}AlN$, $Ti_{2-3}AlC$, and $Ti_{2-3}AlCN$ respectively) with an oxygen content preferably in the range from 8% to 20% by weight as a raw material powder for the bonding phase, these compounds appear to

decompose during the high pressure sintering process and react with the c-BN.

In this reaction, one or more of TiC, TiN and TiCN, one or more of Al_2O_3 and aluminum nitride (denoted hereunder as AlN), and titanium boride (denoted hereunder as TiB₂) is formed, these compounds making up the bonding phase, and having extremely fine crystal grain sizes of not more than 1 micron. At the same time, the c-BN high pressure sintered ceramics is formed with the c-BN dispersed phase having a crystal grain size of less than 1 micron. The above noted results (1), (2) and (3) of these experiments were known by the inventors but not to the public.

By making the cutting tips from the above mentioned ceramic, the cutting tip is attributed with an extremely high strength, so that even when cutting under severe conditions, damage and chipping (micro crack) of the cutting edge of the cutting tip does not occur. Furthermore, the cutting tip is found to exhibit excellent wear resistance.

SUMMARY OF THE INVENTION

The objective of the present invention is to present a high strength ceramic for cutting tools of high toughness and high resistance to wear and chipping.

The ceramic of the present invention is based on the above experimental results, and consists of a bonding phase, a dispersed phase, and unavoidable impurities, wherein said dispersed phase consists of cubic boron nitride, said bonding phase is 20-48% by volume of the ceramic and consists of a decomposed reaction phase obtainable by reacting cubic crystal boron nitride and one or more of titanium aluminium carbide, nitride and carbonitride having an oxygen content, said decomposed reaction phase consisting of titanium boride, aluminium oxide or aluminium oxide and aluminium nitride, and one or more of titanium carbide, titanium nitride and titanium carbonitride, characterised in that said oxygen content is in the range from 2 to 18% by weight, and the crystal grain size in the bonding phase and in the dispersed phase is less than 1 micron.

In this ceramic, the decomposed reaction phase consists of TiB₂, Al_2O_3 or Al_2O_3 and AlN, and one or more of TiC, TiN and TiCN.

The range limits of 20-48% by volume for the bonding phase in the c-BN high pressure sintered ceramics of the present invention for the manufacture of cutting tips are set for the following reasons. The lower limit of 20% is set because if the percentage by volume is less than 20%, the proportion of c-BN becomes large exceeding 80% and resulting in a pronounced drop in the toughness. On the other hand, if the percentage by volume exceeds 48%, the proportion of c-BN in effect becomes less than 52% so that the desirable excellent wear resistant properties cannot be maintained.

With the ceramic tip of the present invention, the crystal grain size in the bonding phase and dispersed phase of the c-BN high pressure sintered ceramic should be not greater than 1 micron. The reason for this is that, as mentioned before, if either of the bonding phase or dispersed phase have coarse grains with grain sizes over 1 micron, then, in particular when cutting under extremely severe conditions, the coarse grains act as a starting point for the occurrence of damage and chipping of the cutting edge.

In the sintering process for the ceramic of the present invention, when using one or more of titanium aluminium nitride, carbide, or carbonitride compounds (denoted hereunder as $Ti_{2-3}AlN$, $Ti_{2-3}AlC$, and $Ti_{2-3}AlCN$ respectively) with an oxygen content preferably in the range from 5% to 15% by volume, as a raw material powder for the bonding phase component, these compounds are decomposed during the high pressure sintering process and react with the c-BN.

In this reaction, one or more of TiC, TiN or TiCN, and one or more of Al_2O_3 and aluminium nitride (denoted hereunder as AlN), and titanium boride (denoted hereunder as TiB₂) is formed, these compounds making up the bonding phase, and having an extremely fine crystal grain size of not more than 1 micron. At the same time, the c-BN high pressure sintered material is formed with the c-BN dispersed phase having a crystal grain size of less than 1 micron.

By making the cutting tips from the above mentioned material, the cutting tip is attributed with an extremely high strength, so that even when cutting under severe conditions, damage and chipping (minute fractures) of the cutting edge of the cutting tip does not occur. Furthermore, the cutting tip is found to exhibit excellent wear resistance.

Brief Description of the Drawings

Figure 1 is an X ray diffraction diagram of a sample of tool ceramics according to the present invention after sintering.

Examples

As follows is a description of actual examples of ceramics for cutting tip manufactured according to the present invention.

In the manufacturing process, at first wet type pulverized mixing of respective $Ti_{2-3}AlN$, $Ti_{2-3}AlC$ and $Ti_{2-3}AlCN$ powders

is carried out in a ball mill with 0.2 mm to 1.5 mm diameter balls made of tungsten carbide.

Then, an oxidation process is carried out on the mixture by holding the mixture for one hour at a predetermined temperature within the range from 200°C to 400°C in an atmosphere of oxygen and argon gas, the oxygen having a partial pressure within the range of 0.005% to 1%, to prepare the respective Ti_2AlN , Ti_2AlC and Ti_2AlCN raw material powders for the bonding phase, with oxygen contents as shown in the Table 1.

The respective powders are then combined with the c-BN powder as the raw material powder for forming the dispersed phase, in the proportions shown in the same Table 1, using a centrifuge to classify the powders so that none of the grain sizes exceeds 1 micron. The powders are then wet mixed in a ball mill under the same conditions as before-mentioned, and dried.

After this, the respective powders are press molded on support tips at 2 ton/cm² to form pressed powder bodies, the support tips being made of tungsten carbide with 10% by weight of cobalt, and having dimensions of 10 mm diameter and 2 mm thickness. The pressed powder bodies and support tips are then placed together in an high pressure sintering apparatus and sintered at a pressure of 6.2 GPa and a temperature of 1500°C.

In this way the ceramics of the present invention were obtained having the dispersed phase and bonding phase proportions substantially the same as the compound proportions. Specimens of these ceramics were manufactured into cutting tips 1 to 13 with thicknesses as shown in Table 1.

In addition, sintered bodies having compositions similar to the respective cutting tips 2, 4, 5 and 6, were cut up with a wire electric discharge process and then polished with a diamond grindstone (finished with # 1200 diamond grindstone) to obtain 12 mm long test pieces 1 mm in depth and 2 mm wide. The bending strength of these test pieces was then determined by carrying out a three point bend test over a 10mm span. These results are also shown in Table 1.

Table 1

Cutting tips of present invention	Compound Composition (vol %)				Thickness (mm)	Bending strength (MPa)
	Bonding phase component powder			c-BN powder		
	Composition	Oxygen content (weight %)				
1	Ti ₂ AlN	12	30	70	1.5	-
2	Ti ₂ AlC	12	45	55	1.5	1190
3	Ti ₂ AlN	12	40	60	1.0	-
4	Ti ₂ AlC	12	35	65	1.5	1240
5	Ti ₃ AlN	12	40	60	1.5	1020
6	Ti ₂ AlCN	12	40	60	1.5	1050
7	Ti ₂ AlCN	12	48	52	2.5	-
8	Ti ₃ AlN	18	10	80	1.5	-
9	Ti ₂ AlC	8	10 (20)			-
	Ti ₂ AlC	14	15	70	1.5	-
	Ti ₂ AlCN	10	15 (30)			-
10	Ti ₂ AlN	8	10			-
	Ti ₂ AlC	10	10	65	1.5	-
	Ti ₂ AlCN	12	15 (35)		1.5	-
11	Ti ₂ AlN	5	40	60	1.5	-
12	Ti ₂ AlC	3	45	55	1.5	-
13	Ti ₂ AlN	2	30	70	1.5	-

In order to compare the results for the cutting tips of the present invention with those made from the conventional materials, powdered TiC , TiN , $TiCN$, Al_2O_3 , AlN , TiB_2 and c-BN with the grain sizes controlled so as not exceed 1

micron were prepared as raw material powders. These were mixed according to the mixture compositions shown in Table 2 with other conditions the same as for the previous preparations. Conventional cutting tips 1 to 10 as shown in Table 2 having compositions substantially the same as the previous mixture compositions were then manufactured.

In addition, sintered bodies having the same composition as the conventional cutting tips 2 and 5 were subjected to the bending test in a similar manner to that beforementioned, and the bending strength obtained. The results are shown in Table 2.

Table 2

Conventional cutting tips	Mixture composition (vol %)							thickness (mm)	bending strength (MPa)
	TiC	TiN	TiCN	Al ₂ O ₃	AlN	TiB ₂	c-BN		
1	-	20	-	5	-	5	remainder	1.5	-
2	30	-	-	5	-	2	"	2.0	800
3	-	20	-	10	-	10	"	1.0	-
4	20	-	-	10	-	5	"	1.5	-
5	-	10	-	15	-	10	"	0.5	750
6	-	-	30	5	-	5	"	1.5	-
7	-	-	23	15	5	5	"	2.2	-
8	5	5	-	-	5	5	"	2.5	-
9	5	-	5	5	-	15	"	1.5	-
10	5	5	10	5	-	5	"	1.5	-

With regards to the results obtained for the various cutting tips, the bonding phase were measured by X-ray diffraction, and the c-BN and bonding phase maximum crystal grain sizes were measured.

In manufacturing the various cutting tips, the c-BN sintered ceramics was cut up into six segment pieces by the electric discharge machine, and these were soldered to a tungsten carbide base, and ground to form throw away tips having a TPGA322 profile.

Cutting tests were carried out under the following conditions (referred to as "A" cutting conditions below) involving high speed interrupted finishing cutting of carburized hardened steel.

Work piece: SCr415 (surface hardness: HR C 62) cylindrical bar having 8 evenly spaced longitudinal grooves formed around the periphery thereof.

Cutting speed: 250 m/min

Feed rate: 0.1 mm/ rev

Cut depth: 0.1 mm

Cutting time: 10 mins

Subsequently, cutting tests were carried out under the following conditions (referred to as "B" cutting conditions below) involving high speed interrupted finishing cutting of carburized hardened steel.

Work piece: SCM418 (surface hardness: HR C 55) cylindrical bar having 8 evenly spaced longitudinal grooves formed around the periphery thereof.

Cutting speed: 150 m/min

Feed rate: 0.4 mm/ rev

Cut depth: 0.1 mm

Cutting time: 10 mins

The wear widths of the respective cutting edge relief surfaces were measured for each of the tests. The results of these measurements are shown in Tables 3 and 4.

As shown in Tables 1 to 4, the cutting tips 1 to 13 of the present invention both have crystal grain sizes for the c-BN and bonding phase of less than 1 micron. Consequently, due to the resultant high strength, damage and chipping of the

cutting edge did not occur even under severe conditions of high speed interrupted finishing cutting of high strength steel, and interrupted finishing cutting with high feed rates. Furthermore, the cutting tips showed excellent resistance to wear.

With the comparative cutting tips 1 to 10 shown in Table 2 and Table 4, in spite of using raw material powders having grain sizes not exceeding 1 micron, grain growth during the extreme pressure sintering process resulted in crystal grain sizes exceeding 3 microns. As a result, the strength of the comparative cutting tips 1 to 10 was inadequate so that chipping occurred under the beforementioned extreme conditions, and the useful life of the cutting tip was reached in a short time.

With the cutting tips of the present invention made from high strength c-BN high pressure sintered ceramics, the tip strength was found to be adequate for high speed and heavy cutting conditions. Furthermore, the tool exhibited excellent features relevant to industrial use, such as resistance to damage and wear over remarkably long periods.

The X-ray diffraction test results for specimens of the examples of Table 1 taken after sintering are shown in Fig. 1.

Figure 1 shows the X-ray diffraction chart for after sintering. Comparing this with the starting materials shows that the Ti_2AlC peak has disappeared. Also there are a new AlN peak, a TiB_2 peak and a TiC peak appears strong.

The above results show that, the Ti_2AlC carbide compound of titanium and aluminum is decomposed into the titanium carbide (TiC) under the high temperature and high pressure sintering conditions, and at the same time, TiB_2 and ALN were formed due to the existence of c-BN.

Table 3

Cutting tips of present invention	Bonding phase	maximum crystal grain size (microns)		relief surface wear(mm)	
		c-BN	bonding phase	A	B
1	TiN, Al_2O_3 , TiB_2	0.6	0.4	0.07	0.06
2	TiC, TiB_2 , Al_2O_3	0.7	0.5	0.08	0.05
3	TiN, Al_2O_3 , TiB_2	0.3	0.5	0.06	0.08
4	TiC, Al_2O_3 , TiB_2	0.5	0.4	0.08	0.05
5	TiC, Al_2O_3 , TiB_2	0.9	0.4	0.08	0.06
6	TiN, Al_2O_3 , TiB_2	0.6	0.4	0.06	0.06
7	TiCN, Al_2O_3 , AlN TiB_2	0.7	0.6	0.10	0.11
8	TiC, AlN, TiB_2 , TiCN	0.7	0.6	0.11	0.12
9	TiCN, Al_2O_3 , TiB_2	0.7	0.3	0.07	0.07
10	TiCN, Al_2O_3 , TiB_2	0.5	0.3	0.08	0.09
11	TiN, AlN, TiB_2	0.7	0.6	0.12	0.13
12	TiC, Al_2O_3 , AlN, TiB_2	0.7	0.9	0.12	0.15
13	TiN, AlN, TiB_2	0.5	0.9	0.14	0.15

Table 4

Conventional cutting tips	Bonding phase	maximum crystal grain size (microns)		time until chipping(min)	
		c-BN	bonding phase	A	B
1	TiN, Al ₂ O ₃ , TiB ₂	0.6	4	3	7
2	TiN, TiN, TiB ₂	0.9	8	1	3
3	TiN, Al ₂ O ₃ , TiB ₂	0.3	4	3	7
4	TiC, Al ₂ O ₃ , TiB ₂	0.5	3	3	7
5	TiC, Al ₂ O ₃ , TiB ₂	0.9	6	2	5
6	TiCN, Al ₂ O ₃ , TiB ₂	0.6	4	3	7
7	TiCN, Al ₂ O ₃ , AlN, TiB ₂	0.7	6	2	5
8	TiC, TiN, AlN, TiB ₂	0.7	8	1	3
9	TiC, TiCN, Al ₂ O ₃ , TiB ₂	0.7	4	3	6
10	TiCN, Al ₂ O ₃ , TiB ₂	0.5	4	3	7

Claims

1. A cubic boron nitride-based sintered ceramic for cutting tools consisting of a bonding phase, a dispersed phase, and unavoidable impurities, wherein said dispersed phase consists of cubic boron nitride, said bonding phase is 20-48% by volume of the ceramic and consists of a decomposed reaction phase obtainable by reacting cubic crystal boron nitride and one or more of titanium aluminium carbide, nitride and carbonitride having an oxygen content, said decomposed reaction phase consisting of titanium boride, aluminium oxide or aluminium oxide and aluminium nitride, and one or more of titanium carbide, titanium nitride and titanium carbonitride, characterised in that said oxygen content is in the range from 2 to 18% by weight, and the crystal grain size in the bonding phase and in the dispersed phase is less than 1 micron.
2. A cubic boron nitride-based sintered ceramic for cutting tools according to claim 1, wherein said titanium aluminium carbide is Ti₂₋₃AlC.
3. A cubic boron nitride-based sintered ceramic for cutting tools according to claim 1 or 2, wherein said titanium aluminium nitride is Ti₂₋₃AlN.
4. A cubic boron nitride-based sintered ceramic for cutting tools according to claim 1, 2 or 3, wherein said titanium aluminium carbonitride is Ti₂₋₃AlCN.
5. A cubic boron nitride-based sintered ceramic for cutting tools according to any preceding claim wherein said decomposed reaction phase consists of TiB₂, Al₂O₃ or Al₂O₃ and AlN, and one or more of TiC, TiN and TiCN.

Patentansprüche

1. Sinterkeramik auf der Basis von kubisch kristallinem Bornitrid für Schneidwerkzeuge, die aus einer Bindephase, einer dispergierten Phase und unvermeidbaren Verunreinigungen besteht, wobei die dispergierte Phase aus kubisch kristallinem Bornitrid besteht; die Bindephase 20 bis 48 Vol.-% der Keramik ausmacht und aus einer Zersetzungsreaktionsphase besteht, die durch Umsetzung von kubisch kristallinem Bornitrid mit einer oder mehreren der Verbindungen Titan-Aluminium-Carbid, -Nitrid und -Carbonitrid, die einen Sauerstoffgehalt haben, erhältlich ist; die Zersetzungsreaktionsphase aus Titanborid, Aluminiumoxid oder Aluminiumoxid und Aluminiumnitrid und einer oder mehreren der Verbindungen Titancarbid, Titanitrid und Titancarbonitrid besteht, dadurch gekennzeichnet, daß der Sauerstoffgehalt im Bereich von 2 bis 18 Gew.-% liegt und die Kristallkorngröße in der Bindephase und in der dispergierten Phase weniger als 1 µm ist.

2. Sinterkeramik auf der Basis von kubisch kristallinem Bornitrid für Schneidwerkzeuge gemäß Anspruch 1, in der das Titan-Aluminiumcarbid $Ti_{2-3}AlC$ ist.
3. Sinterkeramik auf der Basis von kubisch kristallinem Bornitrid für Schneidwerkzeuge gemäß Anspruch 1 oder 2, in der das Titan-Aluminiumnitrid $Ti_{2-3}AlN$ ist.
4. Sinterkeramik auf der Basis von kubisch kristallinem Bornitrid für Schneidwerkzeuge nach Anspruch 1, 2 oder 3, in der das Titan-Aluminium-Carbonitrid $Ti_{2-3}AlCN$ ist.
5. Sinterkeramik auf der Basis von kubisch kristallinem Bornitrid für Schneidwerkzeuge nach einem der vorangehenden Ansprüche, in der die Zersetzungsreaktionsphase aus TiB_2 , Al_2O_3 oder Al_2O_3 und AlN und einer oder mehreren der Verbindungen TiC , TiN und $TiCN$ besteht.

Revendications

1. Céramique frittée à base de nitrure de bore cubique pour outils de coupe constituée d'une phase de liaison, d'une phase dispersée, et des impuretés inévitables, dans laquelle ladite phase dispersée est constituée de nitrure de bore cubique, ladite phase de liaison est 20-48 % en volume de la céramique et est constituée d'une phase de réaction décomposée pouvant être obtenue en faisant réagir le nitrure de bore cristallin cubique et un ou plusieurs du carbure de titane et d'aluminium, d'un nitrure et d'un carbonitride ayant une certaine teneur en oxygène, ladite phase réactionnelle décomposée étant constituée de borure de titane, d'oxyde d'aluminium ou d'oxyde d'aluminium et de nitrure d'aluminium et un ou plusieurs du carbure de titane, du nitrure de titane et du carbonitride de titane, caractérisé en ce que ladite teneur en oxygène est dans la gamme de 2 à 18 % en poids, et le diamètre des grains cristallins dans la phase de liaison et dans la phase dispersée est inférieur à 1 micromètre.
2. Céramique frittée à base de nitrure de bore cubique pour outils de coupe selon la revendication 1, dans laquelle ledit carbure de titane et d'aluminium est $Ti_{2-3}AlC$.
3. Céramique frittée à base de nitrure de bore cubique pour outils de coupe selon la revendication 1 ou 2, dans laquelle ledit nitrure de titane et d'aluminium est $Ti_{2-3}AlN$.
4. Céramique frittée à base de nitrure de bore cubique pour outils de coupe selon la revendication 1, 2 ou 3, dans laquelle ledit carbonitride de titane et d'aluminium est $Ti_{2-3}AlCN$.
5. Céramique frittée à base de nitrure de bore cubique pour outils de coupe selon l'une quelconque des revendications précédentes, dans laquelle ladite phase de réaction décomposée est constituée de TiB_2 , Al_2O_3 ou Al_2O_3 et AlN , et un ou plusieurs de TiC , TiN et $TiCN$.

FIG. 1

